Using design considerations given in the section above and equations outlined in published texts relating to nozzles, a bench sale reactor was constructed for synthesis of titanium, vanadium, aluminum, and TiN Alloys. This equipment was designed for operation at 12 KW input power to the plasma torch, using a plasma gas flow of 50 scfh and a plasma gas made up of 95% argon and 5% hydrogen gas. The equipment used to produce these materials consisted of a small bench scale plasma torch operated at 12 kW electrical input power attached to a reactor section, quench nozzle, cyclone powder collector, liquid nitrogen cold trap to collect by-product HCL and mechanical vacuum pump.

To produce titanium metal particles, titanium tetrachloride was heated above its boiling point and injected into the reaction chamber at the junction between the plasma torch and the reaction section. The reaction section, quench nozzle, and expansion chamber were constructed of water cooled nickel. The reaction section was 11.0 mm inside diameter and 150.0 mm in length. The quench nozzle section consisted of a high aspect ratio converging section followed by a 6.2 mm nozzle, and 12° included angle expansion section followed a 20.0 mm I.D., 50.0 cm cool down section. The cooled mixture of titanium powder and gas was passed through two sonic cyclone particle separators to collect the ultrafine powder. Hydrogen chloride vapor was condensed out in a liquid nitrogen cooled cold trap to prevent damage to the mechanical vacuum pump down stream from the particle collection. Titanium was produced according to equation (1) below:

$$TiCl_4(g)+2H_2(g)+T>3000^\circ\ C.\rightarrow Ti(s)+2HCl(g)$$

Ultrafine vanadium metal powder was produced using the bench scale apparatus described above. Vanadium tetrachloride liquid (B.P 145° C.) was heated to vapor and injected in the same manner as titanium tetrachloride described above with hydrogen carrier gas. Ultrafine vanadium metal powder was produced at the rate of a 0.5 gram per hour according to one of the following equations:

$$2VCl_3(g)+3H_2(g)+T>3000^\circ\ C.\rightarrow 2V(s)+6HCl(g)$$

$$VCl_4(g)+2H_2(g)+T>3000^\circ\ C.\rightarrow V(s)+2HCl(g)$$

An ultrafine powder consisting of an alloy of titanium and vanadium was produced by two methods. Method **1** used a mixture of solid vanadium trichloride dissolved in liquid titanium tetrachloride. This mixture was then heated to vapor and injected into the plasma quench reactor in the same manner as with titanium above. In Method **2**, vaporized liquid vanadium tetrachloride and vaporized liquid titanium tetrachloride were injected into the plasma quench reactor using separate injectors locate**1** in the same axial position but 180° apart on the circumference of the reactor. The chemical equations used are:

$$10TiCl_4(g)+2VCl_3(g)+23H_2(g)+T>3000^\circ\ C.\rightarrow 10Ti(s)+2V(s)+46HCl(g)$$

$$5TiCl_4(g)+VCl_4(g)+12H_2(g)+T>3000^\circ\ C.\rightarrow 5Ti(s)+V(s)+24HCl(g)$$

Ultrafine aluminum metal powder was produced by vaporizing (subliming) solid aluminum trichloride in a specially designed oven and carried into the plasma quench reactor in a stream of hydrogen gas in the manner described for titanium above. Special care was needed to insure all sections of the injection system were maintained above 200° C., to prevent formation of solid aluminum trichloride. The process utilized the following equation:

$$2AlCl_3(g)+3H_2(g)+T>3000^\circ\ C.\rightarrow 2Al(s)+6HCl(g)$$

In compliance with the statute, the invention has been described in language more or less specific as to the experimental mental equipment and methodical features. It is to be understood, however, that the invention is not limited to the specific features described, since the means herein disclosed comprise preferred forms of putting the invention into effect. The invention is, therefore, claimed in any of its forms or modifications within the proper scope of the appended claims appropriately interpreted in accordance with the doctrine of equivalents.

We claim:

1. A fast quench reactor for thermal conversion of one or more reactants in a thermodynamically stable high temperature gaseous stream to a desired end product in the form of a gas or ultrafine solid particles, comprising:

a reactor chamber having axially spaced inlet and outlet ends along a reactor axis;

[a**]** high temperature heating means positioned at the inlet end of the reactor chamber;

a reactant stream inlet for introducing a stream comprising at least one reactant within the reactor chamber where said stream is heated by said high temperature heating means to produce a hot gaseous stream flowing axially toward the outlet end of the reactor chamber;

the reactor chamber having a predetermined length sufficient to effect heating of the reactant stream by the high temperature heating means to a selected equilibrium temperature at which a desired end product is available within the reactant stream as a thermodynamically stable reaction product at a location adjacent the outlet end of the reaction chamber;

a convergent-divergent nozzle located coaxially within the outlet end of the reactor chamber for rapidly cooling the gaseous stream by converting thermal energy to kinetic energy as a result of adiabatic and isentropic expansion as the gaseous stream flows axially through the nozzle, *the convergent-divergent nozzle having a converging section and a diverging section respectively leading to and from a restrictive open throat, the diverging section having a conical configuration centered along the reactor axis and having an included angle in the range of 6° to 14°*; and

a cool down chamber leading from the nozzle for retaining the desired end product within the flowing gaseous stream**[**, and wherein the nozzle and cool down chamber are designed to minimize back reactions**]**.

2. The fast quench reactor of claim **1**, wherein the high temperature heating means comprises a plasma torch, *a plasma torch exit disposed between the plasma torch and the reaction chamber,* and a plasma arc inlet for introducing a stream of plasma arc gas to the plasma torch to produce a plasma within the reaction chamber and extending toward the outlet end of the reaction chamber, the plasma containing at least one reactant, whereby the inlet reactant stream is mixed into the plasma to progressively effect heat transfer between the plasma and a resulting gaseous stream.

3. The fast quench reactor of claim **[2]** *1*, further comprising:

a reactant inlet connected to a source of gas which dissociates at or below the equilibrium temperature to produce the desired end product.

4. The fast quench reactor of claim **[2]** *1*, further comprising:

separate reactant inlets respectively connected to sources of two different gaseous reactants which react with one another at or below the equilibrium temperature to produce the desired end product.

5. The fast quench reactor of claim **[2]** *1*, wherein the minimum temperature within the reactor chamber is between about 1700° C. and about 4000° C.

6. The fast quench reactor of claim [2] *1*, wherein the maximum temperature of the gaseous stream exiting the nozzle is less than about 500° C.

7. The fast quench reactor of claim [2] *1*, further comprising:

a reactant inlet operably connected to a source of reactant under positive pressure, whereby the reactant is positively injected into the reactor chamber to penetrate and mix with the plasma.

8. The fast quench reactor of claim [2] *1*, further comprising:

a product collector positioned downstream from the cool down chamber.

9. The fast quench reactor of claim [2] *1*, further comprising:

an external cooling system operably connected to the cool down [section] *chamber*.

10. The fast quench reactor of claim 2, wherein both the *plasma torch* exit [opening] and *the* reactor chamber are coaxially centered along the reactor axis.

11. The fast quench reactor of claim 2, wherein both the *plasma torch* exit [opening] and *the* reactor chamber are coaxially centered along the reactor axis, the width of the reactor chamber being no larger than approximately 200% of the *plasma torch* exit [opening] width.

12. The fast quench reactor of claim 2, wherein both the *plasma* torch exit and *the* reactor chamber are circular in cross section and are coaxially centered along the reactor axis, the diameter of the reactor chamber being in the range of approximately 110% to 150% of the *plasma torch* exit [opening diameter] *width*.

13. The fast quench reactor of claim [2] *1*, wherein [the nozzle has a converging section and a diverging section respectively leading to and from a restrictive open throat;] the converging section of the nozzle [having] *has* a high aspect ratio.

14. The fast quench reactor of claim [2] *1*, wherein [the nozzle has a converging section and a diverging section respectively leading to and from a restrictive open throat;] the converging section of the nozzle [having] *has* a high aspect ratio presented by successive convex and concave surfaces leading into [a] *the* nozzle throat having a circular cross section, the radius of the convex and concave surfaces being approximately equal to the diameter of the nozzle throat.

[15. The fast quench reactor of claim 2, wherein the nozzle has a converging section and a diverging section respectively leading to and from a restrictive open throat; the diverging section of the nozzle having a conical configuration centered along the reactor axis.]

[16. The fast quench reactor of claim 2, wherein the nozzle has a converging section and a diverging section respectively leading to and from a restrictive open throat; the diverging section of the nozzle having a conical configuration centered along the reactor axis with an included angle of less than about 35°.]

[17. The fast quench reactor of claim 2, wherein the diverging section of the nozzle has a conical configuration centered along the reactor axis and having an included angle in the range of 6° to 14°.]

18. The fast quench reactor of claim [2, wherein the nozzle has a converging section and a diverging section respectively leading to and from a restrictive open throat; the fast quench reactor] *1*, further comprising:

an additional inlet leading to the throat of the nozzle for directing an quenching gas into the hot gaseous stream at a rate that condenses a desired reaction product and inhibits formation of other equilibrium products as the resulting hot gaseous stream exits the nozzle.

19. The fast quench plasma reactor for thermal conversion of one or more reactants in a thermodynamically stable high temperature gaseous stream to a desired end product in the form of a gas or ultrafine solid particles, comprising:

an enclosed reactor chamber arranged along a reactor axis, the reactor chamber having axially spaced inlet and outlet ends;

a plasma torch including at least one pair of electrodes positioned at the inlet end of the reactor chamber;

a plasma arc gas inlet upstream from the electrodes for introducing a stream of plasma arc gas between the electrodes at a selected plasma gas flow while the electrodes are subjected to a selected plasma input power level to produce a plasma within the reactor chamber and extending toward the outlet end of the reactor chamber, the plasma containing at least one reactant[, whereby an incoming reactant stream is mixed into the plasma to progressively effect heat transfer between the plasma and a resulting gaseous stream as the gaseous stream flows axially toward the outlet end of the reactor chamber];

at least one reactant inlet leading into the reactor chamber at or adjacent to its inlet end at a selected injection angle*, whereby an incoming reactant stream is mixed into the plasma to progressively effect heat transfer between the plasma and a resulting gaseous stream as the gaseous stream flows axially toward the outlet end of the reactor chamber*;

the reactor chamber having a predetermined length sufficient to effect heating of the gaseous stream by the plasma to a selected equilibrium temperature at which a desired end product is available as a thermodynamically [unstable] *stable* reaction product at a location adjacent the outlet end of the reactor chamber;

a coaxial convergent-divergent nozzle positioned in the outlet end of the reactor chamber for rapidly cooling the gaseous stream by converting thermal energy to kinetic energy as a result of adiabatic and isentropic expansion as it flows axially through the nozzle, the nozzle having a converging section and a diverging section respectively leading to and from a restrictive open throat;

the converging section of the nozzle having a high aspect ratio for accelerating the gaseous stream rapidly into the nozzle throat while maintaining laminar flow;

the size of the restrictive open throat within the nozzle being selected to control the residence time and reaction pressure of the resulting gaseous stream in the reactor chamber;

the gaseous stream being accelerated to sonic velocities during passage through the throat of the nozzle to transform thermal energy of the moving gaseous stream into kinetic energy in the axial direction of gas flow, thereby retaining the desired end product within the flowing gaseous stream;

the diverging section of the nozzle then subjecting the gaseous stream to an ultra fast decrease in pressure by smoothly accelerating and expanding the moving gaseous stream;

a coaxial cool down chamber leading from the diverging section of the nozzle for reducing the velocity of the moving gaseous stream while removing heat energy at a rate sufficient to prevent increases in its kinetic

temperature to retain the desired end product within the gaseous stream; and wherein the diverging section of the nozzle and cool down chamber are designed to minimize undesired side or back reactions; and

a product collector downstream of the cool down chamber to separate a desired reaction product from the gases exiting the cool down chamber.

20. The fast quench plasma reactor of claim 19, further comprising:

an external cooling system operably connected to the cool down [section] *chamber* to remove heat energy from the moving gaseous stream at a rate sufficient to prevent the gas from increasing in kinetic temperature as it traverses the cool down chamber.

21. The fast quench plasma reactor of claim 19, wherein [both] the torch includes a plasma inlet coaxially centered along the reactor chamber axis and both the plasma [inlet] *torch exit disposed between the plasma torch and the reactor chamber and coaxially centered along the reactor chamber axis, and both the plasma torch exit* and the interior of the reactor chamber are circular in cross section.

22. The fast quench plasma reactor of claim [19] *21*, wherein [both the torch includes a plasma inlet coaxially centered along the reactor chamber axis and both the plasma inlet and the interior of the reactor chamber are circular in cross section,] the diameter of the reactor chamber [being] *is* no larger than approximately 200% of the [torch exit] diameter [to prevent recirculation of reaction gases in the reaction chamber] *of the plasma torch exit.*

23. The fast quench plasma reactor of claim [19] *21*, wherein [both the torch includes a plasma inlet coaxially centered along the reactor chamber axis and both the plasma inlet and the interior of the reactor chamber are circular in cross section,] the diameter of the reactor chamber [being] *is* in the range of approximately 110% to 150% of the [torch exit] diameter [to prevent recirculation of reaction gases in the reaction chamber] *of the plasma torch exit.*

24. The fast quench plasma reactor of claim 19, wherein the converging section of the nozzle has [a high aspect ratio presented by] successive convex and concave surfaces leading into [a] *the* nozzle throat, *the nozzle throat* [having] *has* a circular cross section, *and* the radius of the convex and concave surfaces [being] *is* approximately equal to the diameter of the nozzle throat.

25. The fast quench plasma reactor of claim 19, wherein the diverging section of the nozzle has a conical configuration centered along the reactor axis with an included angle of less than 35° for optimum expansion and acceleration of the hot gaseous stream passing through it to minimize undesired size and back reactions.

26. The fast quench plasma reactor of claim 19, wherein the diverging section of the nozzle has a conical configuration centered along the reactor axis with an included angle in the range of 6° to 14° for optimum expansion and acceleration of the hot gaseous stream passing through it.

27. The fast quench plasma reactor of claim 19, further comprising:

an additional inlet leading to the throat of the nozzle for directing a quenching gas into the hot gaseous stream at a rate that condenses desired reaction products and inhibits formation of other equilibrium products as the resulting hot gaseous stream exits the nozzle.

28. The fast quench plasma reactor of claim 19, further comprising:

vacuum means operatively connected downstream of the convergent-divergent nozzle for applying vacuum pressure to the gaseous stream exiting from the nozzle.

29. [An apparatus as set out in] *The fast quench plasma reactor of* claim 19, further comprising:

first cooling means for *cooling* the walls of the reactor chamber to prevent reactions with its materials of construction.

30. [An apparatus as set out in] *The fast quench plasma reactor of* claim 19, further comprising:

first cooling means for *cooling* the walls of the reactor chamber to prevent reactions with its materials of construction; and

second cooling means for *cooling* the convergent-divergent nozzle to prevent reactions with its materials of construction.

31. A method for thermally converting one or more reactants in a thermodynamically stable high temperature gaseous stream to a desired end product in the form of a gas or ultrafine solid particles, comprising the following steps:

introducing a reactant stream at one axial end of a [reaction] *reactor* chamber *having an inlet end and an outlet end, the reactant stream before reaction or thermal decomposition thereof comprising at least one reactant selected from the group consisting of titanium tetrachloride, vanadium tetrachloride, aluminum trichloride and natural gas*;

rapidly heating the incoming reactant stream as the reactant stream flows axially toward the [remaining] *outlet* end of the reactor chamber;

the reactor chamber having a predetermined length sufficient to effect heating of the gaseous stream to a selected reaction temperature at which [a] *the* desired end product is available as a thermodynamically [unstable] *stable* reaction product at a location adjacent the outlet end of the reactor chamber;

passing the gaseous stream through a restrictive convergent-divergent nozzle arranged coaxially within the [remaining] *outlet* end of the reactor chamber to rapidly cool the gaseous stream by converting thermal energy to kinetic energy as a result of adiabatic and isentropic expansion as it flows axially through the nozzle and minimizing back reactions, thereby retaining the desired end product within the flowing gaseous stream; and

subsequently cooling and slowing the velocity of the desired end product and remaining gaseous stream exiting from the nozzle.

32. The method of claim 31, wherein the rapid heating step is accomplished by introducing a stream of plasma arc gas to a plasma torch at the [one axial] *inlet* end of said reactor chamber to produce a plasma within the [reaction] *reactor* chamber which extends toward its [remaining axial] *outlet* end.

33. The method of claim 31, [wherein the step of rapidly cooling the desired end product is accomplished by use of a converging section of the nozzle having a high aspect ratio and] further comprising the following additional step: separating the desired end product from the remaining gases in the cooled gaseous stream.

34. The method of claim 31, wherein the [step of rapidly cooling the desired end product is accomplished by use of] *converging-diverging nozzle has* a converging section [of the nozzle] having a high aspect ratio *and* presented by successive convex and concave surfaces leading into a nozzle throat having a circular cross section, the radius of the convex and concave surfaces being approximately equal to the diameter of the nozzle throat.

35. The method of claim 31, wherein the [step of rapidly cooling the desired end product is accomplished by use of a]

converging-diverging nozzle [having] *has* a converging section and a diverging section respectively leading to and from a restrictive open throat, the diverging section of the nozzle having a conical configuration.

36. The method of claim **31**, wherein the [step of rapidly cooling the desired end product is accomplished by use of a] *converging-diverging* nozzle [having] *has* a converging section and a diverging section respectively leading to and from a restrictive open throat, the diverging section of the nozzle having a conical configuration with an included of less than about 35°.

37. The method of claim **31**, wherein the step of subsequently cooling and slowing the velocity of the resulting desired end product and remaining gaseous stream as it exits from the nozzle is accomplished by directing a quenching gas into the gaseous stream at a rate than condenses [a] *the* desired end product and inhibits formation of other equilibrium products as the resulting gaseous stream exits the nozzle.

38. The method of claim **31**, wherein the desired end product is titanium metal and the [reactants are] *at least one reactant comprises* titanium tetrachloride and hydrogen.

39. The method of claim **31**, wherein the desired end product is vanadium metal and the [reactants are] *at least one reactant comprises* vanadium tetrachloride and hydrogen.

40. The method of claim **31**, wherein the desired end product is aluminum metal and the [reactants] *at least one reactant comprises* are aluminum chloride and hydrogen.

41. The method of claim **31**, wherein the desired end product is a titanium-vanadium alloy and the [reactants are] *at least one reactant comprises* a mixture of titanium tetrachloride, [and] vanadium tetrachloride, [plus] *and* hydrogen, *or a mixture of titanium tetrachloride, vanadium trichloride and hydrogen.*

42. The method of claim **31**, wherein the desired end product is a titanium-boron composite ceramic powder and the [reactants are] *at least one reactant comprises* titanium tetrachloride and boron trichloride.

43. The method of claim **31**, wherein the desired end product is titanium dioxide and the [reactants are] *at least one reactant comprises* titanium tetrachloride and oxygen.

44. The method of claim **31**, wherein the desired end product is acetylene and the [reactants are] *at least one reactant comprises* methane and hydrogen.

45. A method for thermal conversion of one or more reactants in a thermodynamically stable high temperature gaseous stream to a desired end product in the form of a gas or ultrafine solid particles, comprising the following steps:

introducing a stream of plasma arc gas between the electrodes of a plasma torch including at least one pair of electrodes positioned at the inlet end of an axial reactor [chamber,] *chamber having an inlet end and an outlet end,* the stream of plasma arc gas being introduced at a selected plasma gas flow while the electrodes are subjected to a selected plasma input power level to produce a plasma within the reactor chamber and extending toward its outlet end;

thoroughly mixing an incoming reactant stream into the plasma by injecting at least one reactant into the reactor chamber at or adjacent to its inlet end at a selected injection angle and at a selected reactant input rate to progressively effect heat transfer between the plasma and the resulting gaseous stream as it flows axially toward the outlet end of the reactor chamber, *the at least one reactant selected from the group consisting of titanium tetrachloride, vanadium tetrachloride, aluminum trichloride and natural gas;*

the length of the reactor chamber being sufficient to effect heating of the gaseous stream to a selected equilibrium temperature at which a desired end product is available as a thermodynamically [unstable] *stable* reaction product within the gaseous stream at a location adjacent to the outlet end of the reactor chamber;

directing the gaseous stream through a coaxial convergent-divergent nozzle positioned in the outlet end of the reactor chamber to rapidly cool the gaseous stream by converting thermal energy to kinetic energy as a result of adiabatic and isentropic expansion as it flows axially through the nozzle, the nozzle having a converging section and a diverging section respectively leading to and from a restrictive open throat;

cooling the gaseous stream exiting the nozzle by reducing its velocity while removing heat energy at a rate sufficient to prevent increases in its kinetic temperature; and

separating *the* desired end [products] *product* from the gases remaining in the cooled gaseous stream.

46. The method of claim **45**, [further comprising the following step:

accelerating] *wherein the converging section of the nozzle has a high aspect ratio and is configured so that* the gaseous stream *accelerates* rapidly into the nozzle throat while maintaining laminar flow [by passage of the gaseous stream through a converging section of the nozzle having a high aspect ratio].

47. The method of claim **45**, further comprising the following step:

controlling the residence time and reaction pressure of the gaseous stream in the reactor chamber by [selection of] *selecting* the size of the restrictive open throat within the nozzle.

48. The method of claim **45**, [further comprising the following step:

accelerating] *wherein the converging-diverging nozzle is adapted to accelerate* the gaseous stream to sonic velocities during passage through the throat of the nozzle to transform thermal energy of the moving gaseous stream into kinetic energy in the axial direction of gas flow, thereby retaining the desired end product within it.

49. The method of claim **45**, further comprising the following step:

subjecting the gaseous stream to an ultra fast decrease in pressure by smoothly accelerating and expanding the moving gaseous stream along the diverging section of the nozzle to further decrease its kinetic temperature and prevent undesired side or back reactions.

50. A method for producing [titanium,] *titanium or titanium oxide,* comprising the following steps:

decomposing a titanium compound by introducing it as a stream of vapor into a hot plasma together with one or more reactants;

directing the resultant hot gaseous stream through a convergent-divergent nozzle to allow its contents to reach thermodynamic equilibrium prior to being subjected to an ultrafast decrease in pressure; and

quenching [the] titanium *or titanium oxide* within the hot gaseous stream by introducing cold gas into [it] *the hot gaseous stream* as it passes through the nozzle to cool its contents as a rate that condenses titanium *and titanium oxide* and inhibits formation of equilibrium products as the resulting gaseous stream exits the convergent-divergent nozzle.

51. The method of claim **50**, further comprising the step of introducing sufficient carbon to the hot plasma to prevent formation of titanium oxides.

52. The method of claim **50**, further comprising the step of introducing methane to the hot plasma in quantities sufficient to supply adequate carbon to prevent formation of titanium oxides.

53. The method of claim **50**, [further comprising the step of introducing sufficient] *wherein the one or more reactants comprises* oxygen [to the hot plasma] *in an amount sufficient* to produce titanium dioxide as the desired end product.

54. The method of claim **50**, wherein the temperature of the hot plasma is in excess of 4000 K.

55. The method of claim **50**, wherein the *one or more* reactants [include] *comprises* hydrogen.

56. The method of claim **50**, wherein the stream of titanium *compound* vapor is contained within argon as an inert carrier gas *comprising argon*.

57. The method of claim **50**, wherein the hot plasma is maintained at atmospheric pressure and the resulting gaseous stream exiting the convergent-divergent nozzle is at a vacuum pressure.

58. A method of forming a metal, metal oxide, metal alloy, or ceramic from a metal-containing compound, the method comprising the steps of:

(a) providing a plasma formed from a gas comprising an inert gas, hydrogen, or a mixture thereof;

(b) providing a reagent or a reagent mixture, the reagent or reagent mixture comprising a gaseous or volatilized compound of a selected metal;

(c) contacting the reagent or reagent mixture with the plasma for a time and at a reaction temperature sufficient to form an equilibrium mixture comprising the selected metal, metal oxide, metal alloy, or ceramic thereof, the selected metal, metal oxide, metal alloy, or ceramic being thermodynamically stable at the reaction temperature; and

(d) adiabatically and isentropically expanding the equilibrium mixture to rapidly cool the mixture, thereby retaining the selected metal, metal oxide, metal alloy, or ceramic in a cooled product mixture.

59. The method of claim 58, wherein the gaseous or volatilized compound of the selected metal is a gaseous or volatilizable halide.

60. The method of claim 58, wherein the selected metal is titanium, vanadium or aluminum.

61. The method of claim 58, wherein the compound of the selected metal is titanium tetrachloride, vanadium tetrachioride or aluminum trichloride.

62. The method of claim 58, wherein the reagent or reagent mixture further comprises at least one additional reagent capable of reacting at the reaction temperature to form an equilibrium mixture comprising an oxide or alloy of the selected metal.

63. The method of claim 58, wherein the method forms titanium metal, and the reagent or reagent mixture comprises titanium tetrachloride.

64. The method of claim 58, wherein the method forms vanadium metal, and the reagent or reagent mixture comprises vanadium tetrachloride.

65. The method of claim 58, wherein the method forms aluminum metal, and the reagent or reagent mixture comprises aluminum trichloride.

66. The method of claim 58, wherein the method forms an alloy of titanium and a second metal, and the reagent or reagent mixture comprises titanium chloride and a gaseous or volatilizable compound of the second metal.

67. The method of claim 66, wherein the second metal is vanadium.

68. The method of claim 58, wherein the method forms a metal oxide of the selected metal, and the reagent or reagent mixture further comprises oxygen.

69. The method of claim 58, wherein the method forms titanium oxide, and the reagent or reagent mixture comprises titanium tetrachloride and oxygen.

70. A method of forming a desired product from a hydrocarbon, the method comprising the steps of:

(a) providing a plasma formed from a gas comprising an inert gas, hydrogen, or a mixture thereof;

(b) providing a reagent or a reagent mixture, the reagent or reagent mixture comprising a gaseous or volatilized hydrocarbon;

(c) contacting the reagent or reagent mixture with the plasma for a time and at a reaction temperature sufficient to form an equilibrium mixture comprising the desired product, the desired product being thermodynamically stable at the reaction temperature; and

(d) adiabatically and isentropically expanding the equilibrium mixture to rapidly cool the mixture, thereby retaining the desired product in a cooled product mixture.

71. The method of claim 70, wherein the reactant or reactant mixture comprises natural gas.

72. The method of claim 70, wherein the reactant or reactant mixture comprises methane.

73. The method of claim 70, wherein the desired product comprises acetylene.

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